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A REPORT TO THE NATIONAL COMMISSION ON FIRE PREVENTION AND CONTROL

Prepared for the SPI

THE SOCIETY OF THE PLASTICS INDUSTRY, INC.
250 PARK AVENUE
NEW YORK, NEW YORK 10017

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October 1, 1972

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SUMMARY

The consumption of plastics in the United States has grown from 3.5 billion pounds in 1955 to approximately 18 billion pounds in 1970. The rate of growth has been 11 to 13% per year and is expected to continue at least to 1980, at which time an estimated 50 billion pounds of plastics will be consumed annually.

Although plastics and plastics products had become familiar in many applications by 1960, the growth of these materials in building products, appliances and furniture, automotive applications, bottles and other containers in packaging, and in textiles were but a few of the developments in bulk plastics applications that have occurred in the past decade.

To date this growth in plastics has been primarily due to the low cost and freedom of design offered by these materials. Other possibly more significant factors which are expected to contribute to their increased use in a number of applications are those relating to our urgent ecological requirements to reduce our energy and material consumption and significantly decrease our waste discharge into the environment. A recent analysis of energy consumption in basic materials processing has shown that energy demands for producing a ton of plastics are significantly less than for a ton of steel, glass, or aluminum. The unit volume of plastic components or products which can be produced from this ton of plastics is also higher because of its lighter weight. The combination of these factors results in a total energy savings of 60 to 95 percent when plastics are used in place of heavier materials having higher energy demands.

This current and projected use of plastics, worldwide, coupled with increasing social and economic pressures, has brought the issue of fire safety and fire retardance to the attention of government and industry.

Plastics are nominally as combustible as many other conventional materials. Retardation of the tendency of these materials to burn, by addition of flame retarding agents, has been achieved, in part, and efforts within the plastics industry continue on the development of these materials. A still unresolved problem in the use of such fire retardant plastics is that in a real-fire situation, they emit more smoke than do the unretarded plastics. For this reason, they cannot be regarded as the panacea for all plastics' fire problems. Consumption of flame retardant chemicals in the United States, however, grew at an average rate of 13% through the 1960's, reaching a volume of 145.8 million pounds in 1970. This represents an estimated $42 million market for all flame retardant chemical sales (excluding intumescent coatings) or an increase of 100% over the past decade.

In 1961 some 11,700 deaths were attributed to fires in the United States. In 1970, fire killed an estimated 12,200 Americans and destroyed $2.63 billion worth of property. Figures for 1971 show fire deaths have now declined to 11,850. If population changes between 1961 - 1971 are included in the analysis it can be seen that in 1961 the population of the United States was 180 million, in 1970 it was 205 million, and in 1971 a slight increase over this. Calculation of the ratio of fire deaths to population shows that while in 1961 there were 0.065 deaths/1000 population, in 1970 the figure had receded to 0.059/1000. Though an accurate estimate of the 1971 population is not available, the decline in fire deaths and the probable slight increase in population would cause a continued decrease in this ratio.

It is of interest to note that for the period described (1961 to 1971) plastics and plastics products have enjoyed a 11-13%/year growth. It seems logical then to conclude that if, while the plastics industry was undergoing a strong and steady growth, deaths from fire were on the decrease, then plastics involvement in a fire (increasingly likely from 1961 to 1971), if not a deterrent to loss of life, at least is not an exceptional life hazard. Such also appears to be the experience in most of the industrialized countries of the world.

In the United States, building code officials and insurance companies have recognized this steady increased usage of plastics and plastics products and worked to identify what special problems, if any, this class of materials might have. To date, building officials generally have viewed new plastics as they would any new product, basing acceptance on test results where plastics products are classified as to their combustibility and <u>how they will be used</u>.

Smoke and toxic gases from burning materials are two of the major problems facing building officials today. The informed official, however, has been aware of not only the flammability of plastics, but also of their smoke and possible toxic gas contribution to a fire. He has realized that even though under certain test conditions, some burning plastics generate more smoke than conventional materials, that <u>plastics must be evaluated in the configuration of their ultimate use and under conditions relating to that use</u>. In this way, any material, <u>natural or synthetic</u>, can be evaluated more meaningfully and with great relevance to real-world fire conditions.

The insurance rating of plastics and plastics products has been, and generally still is, the same as with other products: either combustible or noncombustible. The primary rating method is the ASTM Tunnel Test. If by this test the material has a flame spread rating of 25 or

below, the material is rated noncombustible; if above, combustible. As yet no firm policy on ignitability of materials, smoke generation, fire endurance, or any of the other parameters key to a fire situation has been promulgated. The general policy revolves around the main problem of identifying the combustibility of the various plastics used in the field and formulating the proper rate.

The unique characteristics and versatility of synthetic materials have led to rapid growth and wide acceptance of plastics and plastics products in a large and diverse number of industrial applications. Displacement within these industries, of conventional materials such as wood or metal has led to some problems in regulatory codes, specifications, and performance criteria. Most of these problems, however, can be traced to a general lack of information on the fire characteristics of the synthetic material in the specific end use application that it serves. This lack, coupled with the general inadequacy of many of the current test methods to relate to real-fire situations, must be resolved if the growth of plastics is to continue as projected.

Test methods used to evaluate the behavior of materials in the fire environment can be divided into two general classes: (1) laboratory methods that are used to gain developmental information on how materials burn, and (2) methods that are used to evaluate the performance of a material in a simulated fire environment to determine its acceptance for a particular use. The examination of the use of standard and accepted test methods requires close attention to the relation between test conditions and real life usage.

Most developmental test methods in use today lack superimposed heating from an external source. A heat flux superimposed on the flaming test piece should provide a thermal environment closer to that of a real fire. Current acceptance tests also appear to neglect, or evaluate in

some dubious fashion, the contribution made to the fire by the material under test. These failings have been recognized and have been receiving considerable research attention. Heat release rate calorimeters, designed to evaluate the heat contributed by a material in a fire to the fire, have been developed at Ohio State University, the National Bureau of Standards, and Stanford Research Institute. With such a device, the relevance of a laboratory technique to real-fire situations will be greatly enhanced, allowing a greater degree of freedom in designing fire safety from small-scale tests. This approach, coupled with increased efforts to develop methods for evaluating the response and life hazards of materials in realistic configurations under realistic fire conditions, is needed to further reduce the fire hazard from all materials, natural or synthetic.

The major causes of death or incapacitation in real-fire situations have been identified as one or all of the following:

- heat and flames
- presence of carbon monoxide
- deficiency of oxygen
- presence of other gases
- presence of smoke
- panic

It has been reported that the toxic products of combustion, while they must be considered for all materials, are for the most part of no greater danger than carbon monoxide, and this compound must be considered in any case. Additionally, because of the complexity of the mixture of combustion products from any given fire situation, plastics and conventional materials should be compared under equivalent conditions for the assessment of their potential hazard to life safety.

The Society of the Plastics Industry has been active in the areas of flammability for some time. From as early as 1962, SPI has sponsored large programs in flammability research and test method development. Presently

SPI, recognizing its ever-increasing responsibility relating to the safe use of plastics, continues to address itself to the problems of defining and minimizing possible hazards associated with plastics flammability.

Specific problem areas currently receiving SPI's attention include the present general lack of correlation between basic science and scale testing and most real-fire situations. SPI has undertaken test programs at several institutions to develop this essential correlation. Other activities have been in the field of education, including dissemination of technical information to, among others, architects, builders, code officals, firefighters and engineers. It is through such a program that SPI hopes to promulgate as much factual data on the flammability characteristics of plastics materials as possible.

In addition to funding research and development efforts in fire research, the SPI plans to continue its educational programs, to assist any regulatory agencies in need of information on plastics, and to strive in every way possible to better define and solve the important problems involved with flammability.

The overall needs in fire prevention and control as associated with synthetic and natural materials can be classified as:

1. The need for <u>systems engineering approach</u>, encompassing detection, warning, venting, and extinguishment modes,
2. The need for <u>relevant scale tests</u> relating to real fires,
3. The need for <u>concerted effort</u> toward standard test development,
4. The need to assess materials <u>as they will be used and in their final configuration</u>,
5. The need for <u>broader education</u> and dissemination of available information, and

6. The need for concerted effort with building officials, government regulatory agencies, user industries, and insurance companies for information exchange, evaluation, study and education.

The response to these needs must include:

1. Further development of a systems engineering approach to the total fire protection problem.
2. Basic research on the mechanisms of fire and fire retardance,
3. Development of new synthetic materials that resist ignition,
4. Implementation of basic biological studies on small and large animals, and
5. Continued and intensified dissemination of relevant fire behavior information, coupled with educational programs on materials, fire prevention and control.

Four major conclusions can be drawn from this study.

1. There is no plastics fire problem; it is instead a materials and use fire problem,
2. Considerable research and development in materials and systems engineering approaches must be accomplished before the fire problem is minimized.
3. Many of the present small scale fire tests appear generally inadequate in their relation to the real world and should be replaced with newer, more meaningful tests, and
4. The only way major progress toward the goal of fire safety will be achieved is through the concerted efforts and close cooperation of the plastics industry, building officials, government regulatory agencies, the fire community, insurance companies, and the community at large.

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I INTRODUCTION

The Society of the Plastics Industry, Inc. (SPI) was organized in 1937 to promote the application and use of plastics. The purpose of the Society, as set forth in the SPI bylaws "shall be to provide leadership for the responsible advancement of the entire plastics industry." The Society, as a not-for-profit organization, in furtherance of this basic purpose also maintains as objectives:

- To represent and serve as the offical spokesman for the plastics industry in the United States;

- To promote the effective use and application of plastics, consistent with the public interest;

- To provide and stimulate authoritative research, education and information within the industry and other industries, government bodies and interested organizations;

- To provide a means of mutual communication and organization of groups within the industry to initiate and pursue programs of common technical marketing or management interest;

- To mobilize and finance voluntary, staff and professional expertise to provide the required range of services to members; and

- To maintain liaison and cooperation with other plastics and allied trade and professional associations in the United States and in other countries throughout the world.

The Society is composed of approximately 1,100 member companies which supply raw materials, process or manufacture plastics or plastics materials, which engineer or construct molds or similar accessory equipment for the plastics industry, and which engage in the manufacture of plastics machinery. It is estimated that the member companies of the Society account for over 75 percent of net total dollar volume of the domestic plastics industry.

The Society embraces approximately 55 separate divisions, sections, and committees that deal with various phases of plastics materials and products. Actually, each of the Society's divisions operates largely as an independent association within the broad framework of the industry.

The primary focal point for the flammability-related activities conducted by the Society has been its Coordinating Committee on the Safe Use of Plastics and the Plastics in Construction Council (PICC). These Committees' objectives are, among other things, to formulate and guide flammability and fire safety policy. They serve in a liaison role with insurance carriers, regulatory agencies, the National Fire Protection Association and other codes and standards organizations.

Other special interest groups of the Society, in concert with the Coordinating Committee on the Safe Use of Plastics, also maintain concentrated efforts at developing and improving the current technical information relative to questions of flammability and plastics products. In this way the SPI, working through its divisions, is able to stay in the forefront of all significant developments in the field. This information is then disseminated in meetings, conferences, and seminars through the Society's divisions and throughout the industry. It is through such an information program, coupled with recommendations for action, that the Society is able to bring about an increasingly responsible and factual view of plastics and plastics products, their safety and advantages.

This report, commissioned by the Society of the Plastics Industry for presentation to the National Commission on Fire Prevention and Control, will include a brief review of plastics growth over the past ten years in the United States and other industrialized countries over the world, of the effect of this growth on the fire problems of these countries, of the real problems as they are viewed by regulatory code and insurance industry officials, and of the fire test methods currently used.

The report is designed to present an overall view of the Plastics Industry and its role in combating the fire problems of materials, both natural and synthetic. It defines areas in which more effort is required and recommends courses of action that need to be taken by the plastics industry, government scientific and regulatory agencies, and the fire community to minimize life hazard in real-life fire situations.

II PLASTIC GROWTH TRENDS

The consumption of plastics in the United States has grown from 3.5 billion pounds in 1955[1] to approximately 18 billion pounds in 1970.[2] The rate of growth has been a steady 11 to 13 percent per year. Such growth is expected to continue until at least the 1980s at which time an estimated 50 billion pounds of plastics will be consumed.[2] On a per capita basis, this means that every person in the United States used about 22 pounds of plastics material in 1955,[3] 77 pounds in 1970, and will be using approximately 215 pounds a year by 1980.[4]

Although total consumption of plastics in the United States surpasses that of any other nation in the world, the United States now ranks third in per capita plastics consumption. In 1970, West Germany consumed 44 kg (97 lb) per capita, Sweden 38 kg (84 lb), the United States 35 kg (77 lb), Japan 32 kg (70 lb), France 23 kg (50 lb), and Italy 20 kg (44 lb).[5] The growth in consumption of plastic materials is expected to continue throughout the world. Table 1 gives an outline of apparent per capita plastics consumption in various countries from 1955 to 1980.

Although plastics and plastics products had become familiar in many applications by 1960, the growth of these materials in building products, appliances and furniture, automotive applications, bottles and other containers in packaging, and textiles were but a few of the developments that have occurred in the past decade.

New areas for plastics applications are continually being uncovered. The development of plastic containers for carbonated beverages appears to be possibly one of the largest areas of plastics penetration by 1980.[6] Polymeric powder coatings, plastic pouches for liquid packaging (motor oil, antifreeze, beer), plastic paper, and plastics used in pollution

Table 1

APPARENT AND PER CAPITA CONSUMPTION
OF PLASTICS MATERIALS, 1955-1980

	1955[1,3]		1965[1,3]		1970		1980	
	MM lb	lb/Capita	MM lb	lb/Capita	MM lb	lb/Capita	MM lb	lb/Capita
Germany	646	12.9	3,403	57.6	7,260[10]	96.8[8]	18,021[14]	286[15]
Sweden	86	11.0	400	51.0	1,060[10]	83.6[8]	-	-
United States	3,616	21.8	10,358	54.1	18,040[2]	77.0[8]	50,000[2]	215[14]
Japan	235	2.6	3,014	30.8	11,000[2]	70.4[8]	46,200[2]	400.6[14]
France	438	6.0	1,500	30.6	3,342[10]	50.6[8]	7,700[13]	139.2[14]
Italy	178	3.7	1,344	26.2	3,199[10]	44.0[8]	-	-
W. Europe	-	-	11,770[12]	-	20,405[12]	-	42,350[12]	267.7[14]
Australia	-	-	345[9]	31.0[9]	818[9]	57.9[9]	2,686[14]	143.0[11]

control, noise abatement and other ecological applications, are but a few of the other products and specific areas in which plastics will gain increasingly greater acceptance over the next few years.

To date, the growth in plastics has been primarily due to the low cost and freedom of design offered by plastics materials. Based on these parameters, further penetration of plastics into existing markets can be expected to continue. Other possibly more significant factors which are expected to contribute to the increased use of these materials in a number of applications are those relating to our urgent ecological requirements to reduce our energy and material consumption and significantly decrease our waste discharge into our environment. The advantages of synthetic materials, such as plastics, over many alternative materials are now becoming apparent. A recent analysis of energy consumption in basic materials processing has shown that the energy demands for producing a ton of plastics are significantly less than for one ton of steel, glass, or aluminum.[7] The unit volume of plastic components or products than can be produced from this same ton of plastic is also higher because of its lighter weight. In many cases, the plastic components will have less than 1/5 the weight of the same component made from an alternate material. The combination of these factors results in a total energy savings of 60 to 95 percent when plastics are used in place of heavier materials having higher energy demands.

The conflict between increasing material usage and improved environmental and life quality is now being assessed. Material and energy requirements are now being analyzed in the context of a total system (cradle to the grave evaluation). The results of these studies indicate that plastic materials contribute extensively to improved life quality, and a continuing healthy growth rate is predicted through 1980.[4]

This greatly increased worldwide use of plastics over the past 20 years, coupled with increasing social and economic pressures, has brought the issue of fire safety and fire retardance to the attention of government and industry. Though all these new materials result from technological progress and offer functional and aesthetic utility not previously available with conventional materials, their "real-life" fire behavior still remains generally misunderstood.

Plastics are nominally as combustible as many other conventional materials; however, being man-made, they are modifiable by man. Retardation of the tendency of these materials to burn, by the addition of flame retarding agents, has been achieved in part, and efforts within the plastics industry continue on the development of these materials. Consumption of flame-retardant chemicals in the United States grew at an average annual rate of 13 percent through the 1960s, reaching a volume of 145.8 million pounds in 1970. This represents an estimated $42 million market--for all flame-retardant chemical sales (excluding intumescent coatings)--or an increase of 100 percent over the past decade.[8]

Major outlets for flame-retardant chemicals for use in materials applications include the construction industry, textiles and fibers, transportation, appliances, and electrical applications, as well as other specialty areas. Since synthetic materials have gained tremendous inroads in these markets, a large percent of flame-retardant chemical production can be seen going into the fabrication of flame-retardant plastics. For this level of usage to continue, however, a significant problem involved with the use of these agents must be resolved. This is that flame retarded plastics, in a real-fire situation, emit more smoke than those plastics not so treated. For this reason then, though flame retardant plastics do act, in part, as deterrents to life hazard in fire situations, they cannot be considered the panacea for all plastics' fire problems.

III THE EFFECT OF PLASTICS GROWTH ON THE FIRE PROBLEM

In 1961 some 11,700 deaths were attributed to fires in the United States. In 1970, fire killed an estimated 12,200 Americans and destroyed $2.63 billion worth of property.[16] These figures, however, unless viewed in the proper perspective can be misleading. A more accurate assessment of the problem is made if population changes between 1961 and 1970 are also included in this evaluation. On this basis, it can be seen that in 1961 the population of the United States was approximately 180 million people, whereas 1970 estimates show it to have grown to 205 million (approximately 1% per year). Calculation of the ratio of fire deaths to population shows that in 1961 there were 0.065 deaths/1000 population, but in 1970 the figure had receded to 0.059/1000.[16] This decrease, though slight, is a more realistic assessment of the situation than the raw figures usually quoted. Figures for 1971 show fire deaths to have reached 11,850.[17] Assuming a concurrent slight rise in population, the ratio will continue its decrease.

It is of interest to note, however, that for the period described (1961-1971) plastics and plastic products have enjoyed an 11 to 13 percent per year growth, finding acceptance for applications in widely diverse areas ranging from building construction through automotive applications to furnishings and appliances, as well as many others. The only correlation possible from these data is that if deaths from fire continue to decrease, even though the contribution to these fires by plastics are unknown, then plastics on the surface appear not to be an exceptional life hazard.

The rapid growth of plastics and plastic products in many industries has far outstripped the proper promulgation of their fire behavior and flammability characteristics. For this reason these materials, being

relatively new and different from conventional materials, have been held suspect in many fire situations.

Though it is well recognized that plastics do burn, probably as well as many of the conventional materials such as wood and paper, it must be recognized that many plastics can be retarded from burning in any but an extreme fire situation, in which even materials such as steel can fail.

The plastics industry has expended extensive effort over a long period of time toward the development of effective means for achieving fire retardance in its products. This effort has become increasingly intensive in recent years in proportion to the growth of plastics usage in both public and private areas where human life safety is a major consideration. The work has produced generally satisfactory results, although some problem areas still remain.

Two classes of plastics must be considered in any discussion of fire and fire retardance--those that are inherently fire resistant and those that are flammable in varying degrees and must be made fire retardant for some applications. The inherently fire-resistant materials, such as the polyimides for example, have been often too costly or not adaptable for certain applications. The industry has strived to develop new plastics or modifications of known plastics with inherent fire resistance to reduce costs and to improve properties.

The ability to produce a variety of fire-retardant plastics for specified applications provides a design versatility that incorporates fire safety not found in many conventional materials. For example, electrical components and small appliances for consumer use have been made of sufficiently fire-retardant plastic materials virtually to eliminate these products as potential sources of household fires. The recent incidence of fires initiated from instant-on television sets, and the rapid, effective

corrective action taken by the plastics industry, is an example of how fire-retardant plastics can contribute to life safety.

Another example of industry's efforts in this direction is the availability of fire-retardant carpet underlay and carpeting that is significantly less susceptible to flash propagation down corridors. The increased use of properly selected fire-resistant products in such applications can act as effective deterrent to loss of life.

The plastics industry recognizes the fire problem as one of the most serious problems materials have to face. The burning behavior of not only plastics and plastics products, but of conventional materials as well, is still not fully understood. Considerable effort in the plastics industry, therefore, as well as in other industries, has been devoted to the study of the fire problem. Aside from numerous well-staffed efforts by individual companies in the plastics and chemicals industry, such efforts can be exemplified by the many fire- and flammability-of-materials research projects under multiclient sponsorship at various research institutes.[18] The long term objectives of these studies must however, include not only the design of synthetic materials that resist ignition to replace the more combustible materials, both synthetic and natural, now in use, but also the development of coordinated systems engineering approaches to handling real-life fire situations.

As the use of plastics increases and they gain greater acceptance in markets such as building construction, furniture, and textiles, new problems will need to be faced. Many plastics, especially those fire retarded by current technology, emit copious amounts of smoke in a real fire situation. Other plastics, when burning, may not smoke more than conventional materials; however, the plastic smoke "smells different." The spectre of the toxicity of the fumes from burning plastics is being actively investigated and, though no strong evidence of such toxic

materials has been found, the smoke problem still needs solution. Alternative approaches to such a solution are currently underway. Scientific studies on smoke and smoke generation are being conducted in a number of laboratories. While investigation of systems engineering approaches to the problems of fire and smoke are being studied by agencies such as the General Services Administration[19] and many regulatory officials throughout the United States.

The systems engineering concept, including early detection, warning, venting, and extinguishment, appears an excellent approach to the problem where possible. The overall view of a fire condition, including life hazard and escape problems, minimization of property loss, early detection or prevention, and all the other aspects of systems engineering involved in a potential fire in a public building, is increasingly more essential as building contents change in character and thus in the characteristics of their burning. With such precautions and preventative methods in force, building contents, which are the cause of the greatest number of fires in public buildings[20] can be varied at will with no increase in life hazard. Additionally, with effective extinguishment systems operational, not only fire but smoke and toxic gas hazards are virtually eliminated, no matter what the material of construction may be.

IV SUMMARY OF FOREIGN EXPERIENCE

In Section II of this report, figures on worldwide usage of plastics were pointed out. These showed that, on a per capita basis, in 1970, West Germany led the world in consumption of plastics and plastics products, using approximately 97 pounds per person. Sweden followed with 87 pounds, the United States with 77 pounds, and then Japan, France, and Italy, with 70, 50, and 44 pounds per person, respectively. These figures, as the ones for the United States, represent a sizable growth in plastics consumption in each of these countries over the past ten years.

Statistics on fire losses in these countries[21] show that these losses, if taken as a percentage of the Gross National Product (GNP) have generally either decreased or remained the same over the same time period. Though it is tempting to use these data to lend credence to the supposition that plastics usage either mitigates against loss of life or at worst produces conditions just as hazardous as conventional materials, the only conclusion which may validly be drawn is that the growth of plastics usage has not effectively increased or decreased fire hazard in these countries.

It is of interest to review briefly the trends, attitudes, and prevention techniques relating to fires and fire losses in some of the more industrialized countries of the world. Though each has its own special problems and methods of handling them, all have experienced the vigorous entry of plastics and plastics products into their marketplace.

In Australia,[22] a considerable portion of the total property lost to fire, was due to a very few fires per year. These occurred in specialized buildings, mainly used for storage of sugar and wool. In public buildings, sprinklering has gained acceptance from an economic as well as life hazard point of view. In fact, current regulations specify that all buildings over 150 feet in height must have complete light-hazard,

automatic sprinkler protection. The same emphasis is placed on fire control by sprinkler protection in New Zealand--particularly for buildings of inferior construction.

In the United Kingdom,[23] fires inside buildings increased by 88 percent between 1957 and 1967. Fire loss statistics show a 10 percent rise, as a percentage of GNP, over roughly the same time span. These figures are especially interesting in the light of the relatively low plastics usage in Britain during that same period. As plastics gain increasing inroads in United Kingdom markets, the major emphasis in combating Britain's fire problems has shifted from the fire-fighting approach to a more coordinated systems approach utilizing automatic detectors and sprinklers with their associated alerting systems, new fire prevention legislation to strengthen existing regulations especially for public buildings and certain residential establishments, and a centrally controlled computer system for storage of information on hazardous substances, legislation and case histories. These developments, coupled with the efforts of the British Fire Research Station, in operation for the past 21 years, and a continuing modernization of equipment and techniques, are expected to assist in decreasing fire losses in the coming years.

In France,[22] the 1970 industrial and commercial fires alone accounted for 2 billion francs in direct and indirect losses. Under the auspices of the National Center of Prevention and Protection, major developments to assist in the curtailment of these losses have included the requirement of permits for use of torches or electric arcs in building construction, the development of a new high expansion foam for fire fighting and the establishment of the Fire Safety Personnel Instruction Center for the education and training of industrial and safety personnel in fire fighting and fire safety. These efforts, coupled with increasingly stronger building codes and the assignment of the liability for a building's fire behavior to the architect and builder, have helped to keep the French

fire loss ratio relatively constant over the past ten years. The entry of plastics mainly as building contents has affected this situation very little, if at all.

The Japanese situation[22] is somewhat different from those already described. In Tokyo, for example, the number of fires per 1000 population equals 0.8, while the national average for Japan is 0.55 (as contrasted with West Virginia, the lowest in the United States at 0.7); however, the death rate/1000 fires in Japan is the highest in the world and is on the increase. A review of the statistics on deaths in Japanese fires shows that 60 percent of the fire deaths were attributed to carbon monoxide poisoning; only 31.5 percent were attributed to burns. The two largest causes for fires were bath water boilers and heating stoves.

Until recent years, Japanese construction materials were largely wood, bamboo, and paper; the fire hazards involved are obvious. In recent years, fire-resistant construction has been on the increase and now more than 60 percent of the buildings constructed yearly are classed as fire resistive. Through legislation, interior finish for ceilings, walls, and other surfaces must be noncombustible or fire retardant. The Ministry of Construction has tested and approved materials rated as (1) fire retardant (general synthetic materials and plastics), (2) semicombustible (composite organic/inorganic materials such as gypsum board), and (3) noncombustible (asbestos, metal). Such materials have been stipulated for use in stated areas within public places, theatres, hotels, and auditoriums.

As Japan's raw materials supplies are further depleted by her increasing population, the shift from natural to synthetic materials has become not only attractive but necessary. It is again interesting to note that as this shift continues the fire losses as a percentage of the GNP have steadily declined. Japan's systems approach to the fire problem,

early detection, prompt alarm, and quick evacuation, coupled with adequate fire-fighting equipment and trained personnel contribute to this decline. New legislation and better use of synthetic materials through design must also be credited with aiding the situation.

Sweden, Norway, and the Netherlands[22] all suffer from increasing fire losses. One prime reason for this appears to be geographic; as these countries all sustain relatively harsh winters, the use of oil, gas, or electrical heaters and stoves is much higher than in many other parts of the world. With increasing population, the increased use of such potentially hazardous items could be expected to result in increased real-life fire problems. Such apparently is the case. The use of wood as the predominant building material in this area of the world probably adds to the problem. Reaction to the situation is slow but steady. Fire protection codes, fire warning and extinguishment systems, and stronger legislation on flammability and acceptance of materials are all under development. Public education on fire safety and materials' hazards has been initiated and an overall responsiveness to combat fire losses seems on the rise.

Current fire testing programs within these and most of the countries in the world vary widely. Sample configuration, sample size, method of ignition, type of ignition, time of ignition, and numerous other testing parameters vary from country to country. Table 2 illustrates, for example, the relative rating of 24 materials by 6 different national standard fire rating tests. From this table it rapidly becomes clear that a material eminently acceptable in one country would be rejected in another. This lack of standardization in testing, leading to results almost comparable to those obtained at random, is further exemplified by Figures 1 and 2.

Table 2

RELATIVE RATING OF 24 MATERIALS BY 6 DIFFERENT NATIONAL STANDARD FIRE RATING TESTS[24]

No.	Material	Thickness m.m.	Treatment	Germany	Belgium	Denmark	France	Nether-lands	England	Average position
1	Flexboard	25	No	9	7	9	10	9	10	5
2	Flexboard	25	Yes	20	19	21	20	17	12	20
3	Hardboard	4	Yes	7	13	14	18	15	16	14
4	Hardboard	4	No	16	20.5	8	2	4	13	12
5	Plywood	6	Yes	10	15	19	9	10	17	15
6	Plywood	20	Yes	14	16	17	13	16	18	17
7	Plywood	6	No	5	6	10	3	8	8	4
8	Plywood	20	Yes	8	10	12	11	11	7	9
9	Particle board	20	No	12	12	13	8	5	3	13
10	Expanded polystyrene	20	No	15	1	4	17	21	1	8
11	Expanded polystyrene	20	Yes	23	5	5	16	23	23	19
12	Phenolic paper laminate	1.5	No	6	9	16	5	12	6	6
12a	Phenolic paper laminate	15	Yes	19	22	15	22	22	14	21
13	Acrylic sheet	3		3	2	22	1	7	22	7
14	Particle board	25	Yes	13	14	11	7	6	9	10
15	Wood wool/cement slab	25	Yes	18	23.5	23	24	24	24	24
16	Phenolic Foam	25	No	24	23.5	1	21	19	19	18
20	P.V.C. sheet	1.5		21	18	10	19	18	21	22
21	Hardboard	12	Yes	22	20.5	24	23	20	15	23
22	Particle board	3.5	No	4	11	2	4	2	2	1
23	Particle board	5	Yes	17	17	3	15	13	20	16
24	Flexboard	10	No	11	3	6	6	3	4	2
25	Polyester/glass laminate	1.5	No	1	8	7	12	1	5	3
26	Polyester/glass laminate	1.5	Yes	2	4	18	14	14	11	11

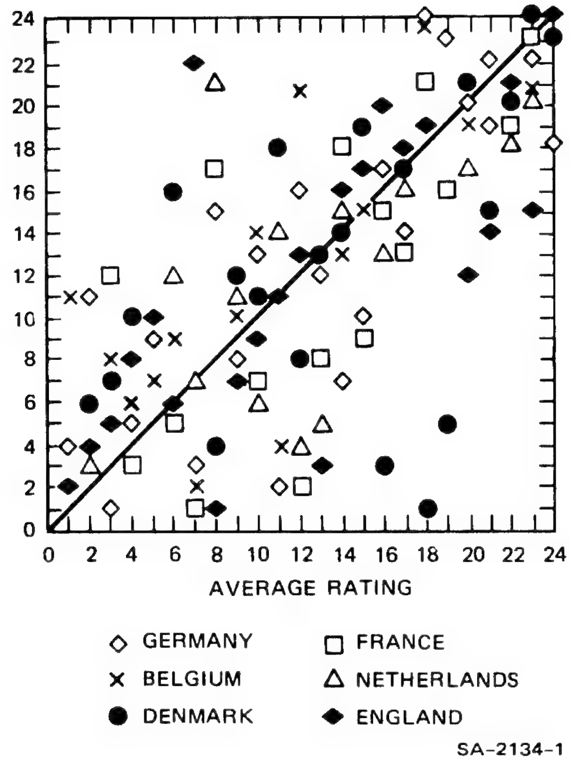

FIGURE 1 COMBUSTIBILITY RATING OF 24 MATERIALS BY 6 STANDARD TESTS[25]

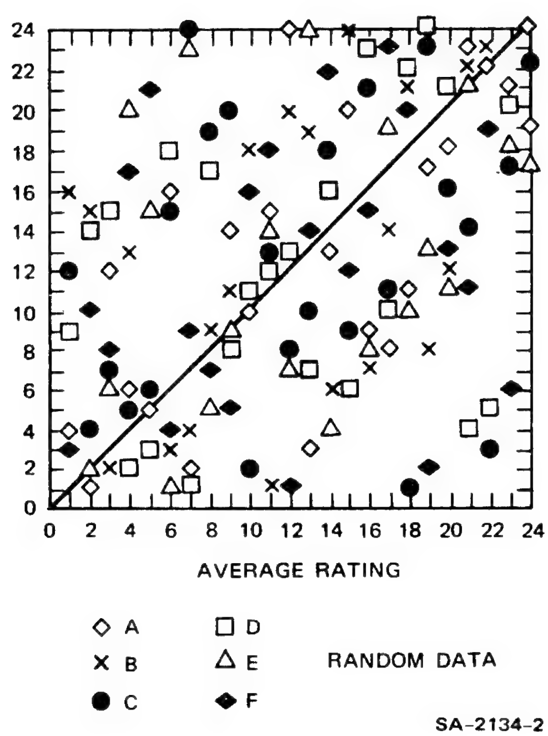

FIGURE 2 RANDOM COMBUSTIBILITY TEST DATA[25]

Correlation between the experience gained in foreign countries and that in the United States would therefore be expected to be difficult to make. Too few countries keep accurate records of their fires, as the emotive conditions surrounding a fire situation tend to make subsequently reported details vague and inaccurate. Testing programs vary tremendously, thus negating any centralized gathering of meaningful data for examination. Fire-fighting techniques vary as does available equipment, adding still another variable to the equation.

V THE FIRE PROBLEM AS PERCEIVED BY BUILDING CODE OFFICIALS

In the United States the building codes or regulations for fire safety have developed over the years. As the use of plastics and plastic products in building construction has grown substantially in recent years and promises to grow even more in the future, building officials have been confronted with a class of materials different from the conventional materials they had been working with. To date, building officials generally have viewed new plastics as they would any new product, basing acceptance on test results where plastics products are classified as to their combustibility and how they will be used. Code changes have been made and many more are now being processed to accomodate new materials for new uses. Implementing code changes is a process of hearings, discussions and reviews of materials. As the code officials become more knowledgeable in the plastics area, these processes take increasingly shorter lengths of time from submission to implementation.

Smoke and toxic gases from burning materials are two of the major problems facing building officials today. The informed official, however, has been aware of not only the flammability of plastics, but also of their smoke and possible toxic gas contribution to a fire for some time. He has realized that even though under certain test conditions, some burning plastics generate more smoke than some conventional materials, that plastics must be evaluated in the configuration of their ultimate use and under conditions relating to that use. In this way, any material, synthetic or natural can be evaluated more meaningfully and with greater relevance to real-world fire situations.

The need for additional information on fire behavior of materials is constant. The greater the fund of information available, the sounder will be the established building code. In the case of plastics, the SPI publication "Plastics/Elastomers Identification Chart,"[26] which identifies criteria such as ease of ignition, character of flame, odor of burning, and

others for most common plastics and elastomers has been made available to all interested code officials, as well as architects, builders, the fire community and many others.

Another need which has been identified is that for more reliable test results. The more knowledgeable officials recognize that present test methods are generally too costly or cumbersome and that acceptable, relevant, small-scale test procedures are needed.

The following list exemplifies some, but by no means all, of the end-use applications plastics and plastics products find in building construction.

<u>Piping and Ducts</u>

water piping, process piping

vent and drain piping

fiber glass ventilation ducts

<u>Wall Construction</u>

window glazing

slip joints and expansion plates

weather stripping, flashing

<u>Lighting Fixtures</u>

diffusers and lenses

outdoor signs, reflectors

outdoor lighting globes

<u>Electrical Wiring and Equipment</u>

transformer cases, induction cases, terminal plates

wiring devices, switch plates, toggles, receptacles

insulation and insulators

Wall Coverings and Panels

spandrel panel sheets

laminates, adhesives, coatings

kickplates, tile

waterproofing

siding, weather stripping, flashing

paints and coatings

Thermal Insulation

walls, roofs

Floor Coverings

composition, tile

carpet and carpet backing

adhesives

Miscellaneous

shower heads, valves, ballcocks

toilet seats

concrete bonding agents, waterproofing

roofing, sealants

gutters and leaders, tapes

joint fillers, vapor barriers

gaskets, vertical binds

various furniture

VI THE FIRE PROBLEM AS PERCEIVED BY THE INSURANCE INDUSTRY

The fire insurance industry and its trade associations have addressed themselves to the fire problems plastic presents for some time. These problems have been viewed as possibly not more severe than conventional materials, but certainly problems different from those encountered with conventional materials. Plastic products have been, and generally still are, as other products, rated for insurance either as combustible or non-combustible. These ratings are generally achieved by the ASTM E84 Tunnel Test (See Section VIII). If by this test the material has a flame spread rating of 25 or below, the material is rated noncombustible; if above, combustible. (This test holds for all materials, not just plastics.) As yet no firm policy has been promulgated on ignitability of materials, smoke generation, fire endurance, or any of the other parameters key to a fire situation. The general policy revolves around the main problem of identifying the combustibility of the various plastics used in the field and formulating the proper premium to cover it.

Individual insurance companies have taken action in limiting or discouraging use of certain kinds of plastics. Generally this action is based on consideration of fire loading, though occasionally it has been initiated after a series of fire losses attributed to these plastics. In many instances plastics or plastics products were not the primary cause of fire and should have been treated as a minor contributor to the loss. This individual treatment of plastics in loss situations can unfortunately be expected to continue until rating organizations develop a formal method of rating the hazard of each plastic in relation to its use. A start has been made in this direction and the Society of the Plastics Industry has worked in full cooperation with the insurance agencies involved. More interchange on a technical level between the plastics industry and insurance organizations is thus being achieved for the formulation of a meaningful rating system.

One of the most prevalent problems in these industries today is that of communications. The plastics industry is beginning to understand the problems of the insurance industry, while the insurance industry begins to understand the needs of the fire protection and code officials. Discussion among these groups is beginning and it could be expected that within the not too distant future, full communication with discussions of fire problems, in their proper perspective, in a language all can understand, will be achieved.

The National Fire Protection Association has recently moved one step nearer to achieving this goal by establishing a new "Tentative Guide for Plastics in Building Construction." This guide, written in close cooperation with the representatives of the insurance industry, recognizes plastics as "...synthetic materials...(which)...have demonstrated distinct superiority in some applications when judged from normal function considerations."

This guide essentially recognizes plastics as a class of materials different from conventional materials such as wood, with their own problems and their own solutions to these problems. It recognizes that the term "plastics" is a generic one and often misleading, and points out that with proper testing and additional research to validate the predictability or correlation of existing tests with real-life situations, plastics can be treated as just another series of materials of construction. It is this kind of development and coordination among industries that will result in more realistic, meaningful attitudes toward plastics usage in the United States and other countries.

VII THE FIRE PROBLEM AS PERCEIVED BY SPECIFIC AREAS IN THE PLASTICS INDUSTRY

The unique characteristics and versatility of synthetic materials, coupled with their low cost and freedom of design, have led to the rapid growth and wide acceptance of plastics and plastics products in a large and diverse number of industrial applications. Displacement within these industries of conventional materials, such as wood or metal, could only have been achieved by synthetic materials that offered more to the consumer than did their predecessors. As these synthetic materials proliferate into widely differing end use applications, each with different operational requirements, a wide variety of potential fire situations are encountered, each one of which must be examined in the proper perspective and handled in a systematic way. The following section points out some of the most significant industrial areas in which plastics materials have gained strong inroads and describes some of the fire problems faced by plastics within that industry.

Plastics in Construction

Housing: Between 1965 and 1971 the consumption of plastics products in building construction has more than doubled, though the plastics share of the market has remained approximately at the 5% level.[27] This figure currently represents a plastics consumption of 3.4 billion pounds.[28] Estimates for 1980 consumption, however, show plastics increasing their share of the market to 10%, or approximately 11.5 billion pounds.[27] This accelerating growth will involve a higher degree of displacement of the more conventional materials of construction by plastics and plastics products. Again, cost, convenience, freedom in design, and aesthetic appeal all are contributing factors to this growth.

As plastics materials gain greater inroads in the building construction markets, an increasing awareness of plastic's response to fire when evaluated in a manner simulating its intended use and configuration is noted. Awareness of parameters such as flame spread, fuel contribution, smoke development and toxicity of combustion products is also becoming more widespread. Initially, the focus for this awareness was the plastic products themselves; however, as the sophistication of the industry increases and the problem of fire is put into its proper perspective, all materials--plastics as well as conventional materials--are being examined and rated on the basis of some of the criteria. Results from these ratings processes have gone far to improve the image of plastics in a fire situation.

Consumption figures for plastics in different segments of the building construction industry for 1971 are:

	Millions of Pounds[28]
Plumbing and Bath Fixtures, Pipe, Fittings, and Conduit	1,253
Insulation	350
Flooring	361
Lighting Fixtures	110
Decorative Laminates	162
Glazing and Skylights	40
Panels and Siding	182
Profile Extrusions (incl. windows, rainwater systems)	100
Resin-Bonded Woods	694
Vapor Barriers	158
Wall Coverings (interior)	93

The fire safety requirements of a building currently vary according to its intended use. Building codes are being written from a performance standpoint rather than specifying materials to be used. This factor has allowed for the more rapid introduction of new materials, such as plastics, in almost all aspects of building construction. A recent example of this situation is the issued standard of the American National Standards Institute (ANSI) Z-97 which requires safety glazing in hazardous locations. This standard when implemented would strongly favor the use of acrylic or polycarbonate sheet.[29]

Though plastics growth is strong in the building industry, competition with conventional materials of construction is still vigorous. Attacks on the alleged hazards of plastics continue, especially in the area of bathrooom components, use of polyvinyl chloride, plastic pipe, and foamed plastics insulation. In each of these areas the plastics industry has closely examined the life hazard of these materials in real-life fire situations. Though no conclusive data have yet been generated, no factual data on any of the materials involved have been reported to indicate that in a real-fire situation plastics would represent a greater hazard than the more conventional materials of construction.

The plastics industry has long realized that as it gains increasing acceptance in the construction industry and as plastics and plastics products find greater usage in areas previously served by some conventional noncombustible materials, the penetration through fire resistive structures might occur. To avoid such a situation for example, the industry has cooperated in a major test program on plastic pipe with the National Bureau of Standards to devise adequate, relevant test methods to maintain fire integrity. Additionally, working with insurance companies and the National Fire Prevention Association (NFPA), representatives of the plastics industry have assisted in establishing a new Tentative Guide for Plastics in Building Construction. This guide written basically with

the strong support of the insurance industry, describes plastics as a class of materials different from conventional materials and suggests methods for their evaluation in realistic terms.

The plastics industry continues to strive to maintain its healthy growth rate and to build its responsible and responsive image. It realizes that one of its major thrusts must be in the development and establishment of relevant testing methods which can be relied on, in any scale, to represent true and real-life fire situations.

Mobile Homes: In 1971 approximately 240 lb of plastics went into each of an estimated 485,000 completed mobile homes. Total consumption of plastics was 120 million pounds, putting the mobile home industry in first place for plastics consumption in the single-family housing market. Predictions for 1972 call for plastics to pass the 150-million-pound market.[30]

To date, penetration of the mobile home industry by plastics and plastics products has occurred only in those instances where definite cost savings could be realized, as compared with alternative materials, or in those cases in which plastics have become accepted as standard building components.

Among other factors increasing plastics usage in mobile homes by a significant degree over the next few years is the adoption of the ANSI Standard Z-97 previously mentioned. This standard will affect storm doors, entrance doors, and shower doors and may increase the plastics stake in the market by approximately 15 million pounds.[30]

ANSI Standard A119.1 sets performance criteria for all mobile homes construction. In relation to fire safety, it defines combustible materials, "...materials made of, or surfaced with wood, compressed paper, plant fibers, or other material which will ignite and burn. The materials

shall be considered combustible even though flame proofed, fire-retardant treated, or plastered." The code furthermore calls for interior walls, partitions, and ceilings to be made of materials whose flame spread classification does not exceed Class C as defined by Section 6-2114 of the Code for Safety to Life from Fire in Buildings and Structures, NFPA No. 101-1970 (flame spread at more than 75 but not more than 200 when tested by ASTM E-84). Currently a sufficient number of plastics materials passing this specification are available and in use. No major problems based on this usage have been noted in recent years.

Plastics in Building Contents

The 1970 distribution of plastics in building contents can be partially described by the following listing:

	Millions of Pounds[28,31]
Carpets and Rugs	1106
Other Textiles (bedding, towels, linens, upholstery, drapes, and curtains)	558
Furniture (including foam)	780
Housewares	948
Toys	651
Major Appliances (refrigerators, home laundry, dishwashers, air conditioners, etc.)	379
Small Appliances (includes vacuum cleaners, countertop blenders and mixers, can openers, radio TV, personal care items)	190

Building construction today, regulated as it is by building codes, tends toward increasing life safety. Building contents, however, free from code restructions or even insurance limitations can vary in quality from noncombustible or highly flammable. Surveys defining the fire hazard

in buildings designed for different occupancies have been conducted by the National Bureau of Standards.[32] By viewing each type of occupancy as a whole, codes can be written to minimize fire hazards present. Using the NBS surveys as a guide, it is therefore possible to estimate the combustible contents of a building and arrive at a figure representing pounds of combustibles per square foot. Though this figure is not adequate to determine the fire loading, it does assist in determining the stringency of the performance requirements of the structure.

Carpeting: From the fire safety point of view, the Flammable Fabrics Act of 1954 (amended in 1967) implemented under Department of Commerce Rule DOC FF 1-70 sets the standards for all carpeting over 24 feet square sold in the United States. This standard went into effect April 16, 1971 and requires that no carpeting be sold unless it passes the fire test specified (See Section VIII). For smaller carpets, DOC FF 2-70 went into effect December 28, 1971 with similar requirements. Carpeting complying with these standards is available to the consumer today.

Bedding: The flammability standard for mattresses, DOC FF 4-72, was issued May 31, 1972 and will go into effect May 31, 1973. This test also appears applicable to upholstery material, defined in the standard as "all material either loose or attached between the ticking, or between the ticking and the core of the mattress..." The mattress standard is designed to significantly decrease the life hazard and burn injuries from mattress fires, rated as one of the major types of single-fatality fires in the United States. According to Secretary of Commerce Peter G. Peterson, only 1 percent of the mattresses marketed today will meet the new standard.[33] Results of these tests conducted at the Fire Research Station, Southwest Research Institute, on 22 bedding materials showed that all burned when ignited.[34] From the data presented, however, it did appear that some

synthetic materials, such as polyurethane, were more difficult to ignite than other more conventional bedding materials, such as cotton ticking, and that while burning they generated considerably less carbon monoxide.

It is expected that more research and development effort will have to be expended by the manufacturers of both synthetic and conventional mattress materials to ensure their fire safety. At this point in time, however, it appears that due to the inherent versatility of synthetic materials, the plastics industry will be able to make a significant contribution to life safety by the development and marketing of mattresses which will readily meet the requirements imposed by this standard.

Appliances: Major and small appliances generally fall under the scrutiny of the Underwriters' Laboratories. This organization and its Seal of Approval has been a major force in the self-policing efforts of the plastics industry. By setting the requirements for the UL Seal of Approval at a high level and maintaining it at that level, the Underwriters' Laboratories has spurred the plastics industry to provide products which either meet or surpass these requirements. The highly favorable consumer attitude toward appliances bearing the UL seal has testified to the success of this action. Additionally, it is of interest to note that by maintaining the standards set forth both by the UL and self-imposed within the industry, no Federal regulations on fire safety for these materials have been required.

Furniture: The estimated value of the 1970 shipments of the furniture industry in the United States was $7.8 billion.[35] These shipments included an estimated 228 million pounds of polyurethane, 250 million pounds of PVC, 85 million pounds of polystyrene, and 5 million pounds of ABS.[28] Estimates for consumer spending this year were $45 billion in home furnishings alone, this to reach $100 billion by 1980.[35]

The cushioning market is currently dominated by polyurethane foam. In 1970, 125 million pounds of flexible foam was used in furniture with 180 million pounds projected for 1975. This growth now looks as if it will be affected by the fire resistance of these materials. At this time, 5% of the total flexible and 60% of the rigid urethane foams are flame retardant.[36]

The case goods market (tables, desks, cabinets, and chests), until recently a predominant user of wood, is now the goal in the competition between wood, metal, nonfoamed plastic, and cellular plastics. No clear data are yet available, but estimates of market growth has been given for cellular plastics in this area of 100% from 1970-1975.[36]

Furniture coverings, traditionally cloth, have switched to use of vinyl and cellular vinyl fabrics. The use of cellular vinyl is expected to increase from 110 million pounds in 1970 to 250 million pounds in 1975.[36]

This strong influx of plastics into the furniture market has brought the fire problem to the attention of both the industry and the consumer. Valid claims have been made that plastic furniture burns differently than furniture prepared from conventional materials, especially plastic products which are meant to imitate wood. Though the burning behavior of these materials can possibly be altered to be less than that of conventional materials, the problems of smoke generation and possible toxicity must still be met. As previously indicated, many companies within the plastics industry directly and indirectly involved with these products are currently vigorously pursuing these problems to learn how to design systems such as those of improved combustibility characteristics. Advances are being made and more fire-resistant systems can be anticipated in the near future.

Plastics in Transportation

Automotive: The use of plastics in automotive applications reached a total of 1.1 billion pounds in 1970.[37] This averages out to 100 pounds per automobile. By 1975 consumption is expected to reach 1.7 billion pounds, while 1980 estimates call for 3.3 billion pounds of plastic materials to be used in automotive products.[27]

With the advent of the 1973 model car year, the Federal Highway Administration's National Highway Safety Administration will begin enforcement of its Motor Vehicle Safety Standard No. 302. This standard relates to the flammability of components found in automobile interiors. The standard requires that certain components included by automobile manufacturers in motor vehicle occupant compartments "must not burn, or transmit a flame, at a rate of more than 4 inches per minute; however, if a material stops burning before it has burned for more than 2 inches from the point where timing was started, the material shall be deemed to have complied with the burn resistance requirements." Interior items covered by the standard include seat cushions, seat backs, seat belts, headlining, arm rests, door panels, instrument panel padding, front and rear side panels, compartment shelves, head restraints, floor coverings, sun visors, curtains, shades, wheel housing covers, engine compartment covers, and mattress covers.

The portion of these components that must meet the 4-inch-per-minute burn test are: (1) the surface material taken separately, (2) a composite nor more than 1/2 in in thickness of surface material bonded to unexposed interior material if such a composite is used in the component, and (3) padding and cushioning material, taken separately.

Application of the test procedures described in Motor Vehicle Safety Standard No. 302 to materials typically used in current automotive applications leads to the following results. Typical automotive upholstery

burns between 3 and 7 inches per minute. For vinyl upholstery, directional effects are usually minimal, while for bodycloth burning rates can vary up to 4 inches per minute in the warp and fill directions. Vinyl-coated cotton headlining (9-10 oz/yd.^{2}) has a wide range of burning rates ranging from 6 to 15 inches per minute. Door-panel material burns at 0 to 10 inches per minute depending on whether the construction is free film (0 burn rate) or a coated fabric. Plasticized vinyl films vary in their burning rates according to their thickness. Polyurethane foams vary according to their density. Unsupported ABS is thick enough where burning rates range between 0.5 and 3 inches per minute.

With these wide variances in results, and with pass/fail decisions being influenced by thickness, density, porosity, or physical movement of the sample during the test, a number of questions have been raised by plastics resin suppliers as to the applicability of the No. 302 test procedure to resinous materials. Additionally, aware of the Bureau's intent in setting the Standard as well as its enforcement procedures, the plastics industry is sensitive to the fact that automobile manufacturers bear responsibility in connection with interior components falling within MVSS No. 302. Moreover, the Industry realizes that these manufacturers must establish a sufficient margin of performance between their test results and the Safety Standard's requirements so as to achieve a reasonable degree of assurance that products manufactured under normal quality control attain burn resistance requirements set forth in MVSS No. 302. Consequently, plastics resin suppliers, among others, are being requested by automobile manufacturers to institute testing procedures that are designed to establish this "sufficient margin" of performance of interior components.

The test procedure recommended in the Standard is generally related to fabricated components or plaques made from these components. As a result, in an effort to assist both the automotive manufacturer and plastics resin supplier, the Society of the Plastics Industry has prepared a guide

for resin suppliers to clarify four key concerns of the industry. This guide attempts to recommend standardized (1) lot size, (2) plaque preparation, (3) plaque dimensions, and (4) standard sampling procedures. If these recommendations are accepted, more definitive results from MVSS No. 302 leading to improved plastic formulations and materials combinations could be expected to result.

As plastics will continue to find a growing market in the automotive industry, it will be with this type of cooperation between resin supplier, automotive manufacturer, government agency, and industry spokesman that increasingly safe products will be manufactured.

Aircraft: The ability of an aircraft and its various systems to withstand the forces involved in a survivable crash is termed "crashworthiness." Implicit in this term is the safe and rapid egress of the survivors from such a crash. Regulatory safeguards for reducing the fire hazard of transport aircraft interior materials are contained in the Federal Aviation Regulations (FAR Part 25, amended October 24, 1967) of the Federal Aviation Administration, known as the FAA flammability test FAR 25.853 (Fed. Spec. 191-5903). This test measures distance of burn, self-extinguishment, and flaming droplets of those materials proposed for use in aircraft.

The growth of plastics in aircraft can be attributed not only to the other properties already defined, but also to their high strength-to-weight ratio. This property, in combination with the design freedom offered by these materials and the inherent nonburning nature of certain plastics, has spurred their growth from 28 million pounds in 1960 to 96 million in 1970. Projections for 1975 and 1980 call for an increase in consumption reaching 150 and 500 million pounds, respectively.[38]

The overall need for the survivor of a crash is exit from the craft. Though the fire hazard in aircraft is indeed important, in this case it may not be more important than the smoke generated from burning materials. Obscuration of means of exit can prove as fatal (if not more so) as the crash itself. For this reason, the FAA working with the industry, uses the NBS smoke chamber (See Section VIII) for determination of smoke generation and ranking of materials. Although considerable work on understanding smoke and means to measure it effectively and reproducibly has already been done by plastics manufacturers and research institutions, no real-life relevancy has yet been achieved. Plastics of low combustibility therefore are gaining some inroads in this market. These materials possess the desirable high strength-to-weight ratio with the added feature of being fire resistant. The rather high cost of these materials, however, will make them subject to a high degree of competition from within the industry, as further understanding of the fire and smoke problems allows the industry to design synthetic materials suitable for this application.

The need to view all factors of a problem, in the proper perspective, is best exemplified in this case, with the concern voiced on interior cabin furnishings, and the apparent lack of low level of concern with other aircraft contents such as large quantities of jet fuel, and non-regulated, non-fire-retarded luggage, comprised mainly of the lower priced grades of plastic, cloth, and paper. It would appear, that within the context of an overall jet crash, such items should be receiving considerably more emphasis in considerations of protecting life and enhancing crashworthiness.

Marine: Due to the nature of the industry and the operational environment of its end product, major fire problems are generally not encountered. The reasons for this include the high degree of awareness

of what a fire at sea would mean and the design of as many parts of a sea-going craft as possible with fire resistance in mind. The greatest inroads of plastics in this market are in the structure (such as the hull) and in interior furnishings. Due to the predominance of polyester resins used for structural applications and the large number of small craft suppliers, statistical data for plastics consumption, when available, tends to be unreliable. It can be stated, however, that it is highly probably that the majority of plastics used are flame retardant and therefore contributing to the life safety of the craft's occupants.

Plastics in the Electrical Industry

In 1971 some 1,239 million pounds of plastics were consumed by the electrical/electronic industry, the majority going into wire and cable applications.[28] As this industry is constantly involved in areas of potential fire hazard, it has become highly sensitive to any fire problems. Because of this sensitivity, and because of the need to meet flammability specifications varying from those for simple hook-up wire to those for wiring commercial aircraft, to the very specialized military and aerospace requirements, the wire and cable/electrical industry is well aware of the numerous tests and requirements relating to fire and actively pursues courses of action that will ensure that its products are acceptable. Though the correlation of this situation to real life is not as close as it should be, competitiveness within the industry mandates a continuing sophistication of products, leading to materials of increased stability and fire safety. For this reason, plastics have found ubiquitous application and near total acceptance in wire and cable and electrical products.

Plastics in Apparel

Total synthetic materials consumption in the apparel field reached over 1,850 million pounds in 1970.[31] Approximately 3% of this total was in nightwear and some smaller portion in children's nightwear, size 6X or below.

Relative to the flammability of fabrics used for apparel, the Flammable Fabrics Act was passed originally in 1953, as a result of fires involving the notorious "torch sweaters" and play suits which caused burn deaths and injuries to several persons. The purpose of that Act was to prohibit the manufacture and sale of such highly flammable items of wearing apparel. It did so by incorporating (by reference) two specific flammability test methods and (by 1954 amendment) modifying one level of performance. It was most unusual, if not unique, that a law would actually incorporate a test method and specify a required performance level.

In 1967, legislation was introduced in the Congress to amend the Act. Having heard testimony that 3,000 to 6,000 people are killed and over 150,000 injured by textile fires each year in the United States,[39] the Congress enacted amendments, and the President signed them into law (PL 90-189) December 14, 1967. Some of the amendments clarified and extended the authority of the Federal Trade Commission and the Bureau of Customs for enforcement of the law. The Secretary of Commerce was authorized to conduct research into the flammability of fabrics, related materials, and products; to conduct studies on the feasibility of reducing their flammability; to develop test methods and devices; and to offer training in the use of these devices. This effort was to be carried out in cooperation with appropriate public and private groups and annual report made to the Congress.

The Secretary of Health, Education, and Welfare was directed to conduct continuing investigations of deaths, injuries, and economic losses resulting from accidental burning of textile products, in cooperation with the Secretary of Commerce, and to report annually to the President and the Congress on these activities.

One of the chief features of the 1967 amendments was a grant of authority to the Secretary of Commerce to establish and modify flammability standards and regulations as needed to protect the public against unreasonable risk of death, injury, or significant property damage. Unlike the 1953 Act, the amendments did not set standards. However, the Secretary was not given unlimited authority. He must determine that there is a need to protect the public, with regard to specific categories of products, and that the standard he sets is needed, reasonable, technologically practicable, appropriate, and is stated in objective terms. He must afford all interested parties the opportunity to participate in the development of standards. He must consult with the National Advisory Committee for the Flammable Fabrics Act. Finally, an adversely affected party may appeal to the courts for judicial review of the Secretary's actions.

On July 29, 1972, DOC FF 3-71, the Children's Sleepwear Standard, became effective. This standard promulgated by former Secretary of Commerce Maurice H. Stans, was designed to eliminate all children's sleepwear from the market which might produce unreasonable risk of death or injury to the child from fire. The standard covers nightgowns, pajamas, and robes, and fabrics intended or promoted for use in sleepwear sizes 0 through 6X manufactured after July 29, 1972. If the garment does not comply, it must carry a warning label. All garments must comply by July 29, 1973.

The plastics industry though responsive to the situation has been concerned about the technological requirements set forth by the standard. Though combinations of materials are available today which will pass the test outlined in the standard--a test which some view with some hesitancy (See Section VIII), the garments produced using these blends of fibers, finishes, and flame retardants appear far from optimal and almost prohibitively expensive. More than $20 million per year is being spent on research in this and other areas relating to textile flammability. Technological advances are foreseen though they are slow in coming.

These problems, as with many others in the fire area, are problems of materials, not just plastics alone. Large segments of the industry supplying textiles for the apparel market are confronted with meeting this standard and will be hard pressed to do so. In this situation, one point is noteworthy; the need for closer liaison between regulatory agencies, which set standards and specifications, and manufacturers and fabricators of the finished item covered by these specifications. Once discussions of the problems involved are carried on among responsible members of both government and industry, the promulgation of standards will be more readily achieved by industry with no loss in life safety.

Plastics in High-Rise Structures

Plastics are not used to a large extent in the structure or finish of a high-rise building; therefore, their fire contribution can be considered minimal. The problems encountered with plastics in high-rise structures seem to be focused on the smoke generation of these materials when used in office furnishings. As previously stated, not only is considerable industrial effort being expended in determining the true nature and problems encountered with smoke, but the development of systems engineering approaches incorporating early detection, venting, sprinklerization,

and planned evacuation of fire areas tends to make smoke less of a life hazard problem than it previously might have been.

Plastics in Industrial Uses

In general, plastics used in industry have not caused many problems, primarily because the amount used does not significantly change the combustible loading. Additionally, the usual industrial building is large enough to accommodate the smoke and toxic products without affecting fire-fighting or endangering personnel.

VIII FIRE TESTS: STANDARD AND ACCEPTABLE METHODS

Test methods used to evaluate the behavior of materials in the fire environment can be divided into two general classes: (1) laboratory methods that are used to gain developmental information on how materials and products burn and how fire retardants may influence burning, and (2) methods that are used to evaluate the performance of a material or product when subjected to an ignition stimulus or to test conditions intended to simulate a fire environment and thereby to determine its acceptance in a particular use. Laboratory developmental tests are usually small scale; the acceptance tests may be either small- or large-scale test configurations. There is no question that properly evaluated information gained from any of these tests is helpful in gaining understanding as to how a material or component responds to fire. But the relation of many of the performance tests to actual conditions of usage is questionable, as they neglect, or at least fall short in their attempt, to evaluate several seemingly critical factors pertinent to life hazards.

Although the importance of physical configuration and thermal environment in the response of a material to fire is generally understood, these factors are not always afforded sufficient consideration when standard tests are used to evaluate performance. It has become increasingly clear that unless a test simulates the fire environment, it cannot yield results relevant to performance in that environment. As more is learned about the inherent combustion behavior of materials and how physical configuration influences combustion, prediction of actual performance from smaller scale tests with greater confidence will be possible. Similarly, tests of improved credibility will be a direct result of the ability to model reliably the fire environment in smaller scale.

Small-scale developmental tests cannot provide generalized measures of performance unless they simulate the physical configuration of the usage and the anticipated fire environment. Yet, judicious observation of how a material responds to the various small-scale test configurations can provide insight as to how that material might be expected to perform in certain specified configurations and environments and if it will be reasonably hazard free.

Test methods designed to guide or regulate the acceptability of material or material systems must realistically evaluate any of the possible hazards to life and property that may result when they are exposed to an actual fire. It is noteworthy, and the fact should be emphasized, that this behavior of a material includes both its <u>response to the fire</u>, measured in terms of its flammability, ignitibility, combustibility, and rate of fire spread, and its <u>contribution to the fire</u>, in heat release, smoke, and toxic gases. An additional requirement, often imposed by building code regulations, recognizes that some material systems used in buildings play a role of containing the fire within the room of its origin. This property is often referred to as its fire resistance but a more generally accepted term now is <u>fire endurance</u>. Basically, it is these three properties of a material--response to the fire, contributing to the fire, and fire endurance--that acceptance test methods attempt to evaluate. Accordingly, a satisfactory acceptance test method must, as a minimum:

(1) Accurately simulate the exposure of a material or a material system to fire effects representative of its actual intended uses

(2) Evaluate contributions of the material to the fire and life hazard environment.

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Some of the more important standard fire-test methods, what they measure, how they relate to real life, and where they succeed and where they seem to fail are discussed below. Important gaps in test methodology where either a critical factor is totally neglected or, as an expediency, is being inadequately treated by contrivance or modification of a test method that was never intended to serve that purpose are noted.

Current Fire Tests

Oxygen Index Test (ASTM D-2863)--The measure of flammability provided by this test is the minimum concentration of oxygen in an oxygen-nitrogen atmosphere that will just sustain the candle-like burning of a plastic rod or strip. Burning is vertical from the upper end of the test piece. This test is reported to yield highly reproducible results and has found ready acceptance as a comparative test among plastic materials. No provisions for measuring burning rate or smoke generation are made in the standard version, but modifications to do both have been used. No consideration is given to the effects of dripping or char formation. As is the case with most small scale tests, the sample is heated only from its own flame and the influence of heating from external fire sources is not measured.

Flammability of Self-Supporting Plastics (ASTM D-635)--Test specimens in the form of molded bars are clamped horizontally. The free end of the specimen is exposed to the flame from a bunsen burner for one or two 30-second intervals. Burning over a limited length of specimen is judged as "self-extinguishing" and burning over a full measured distance is judged as "burning" with an accompanying report of linear burning rate. This test is somewhat subjective and could be misused when materials that melt and drip are tested. Nevertheless, results can be quite useful for comparing ease of ignition and burning rate of plastic materials, and performance can be quite reliably measured for those usages that are simulated by the physical configuration and thermal environment of the test.

Flammability of Plastics: Foam and Sheeting Tests (ASTM D-1692)--This test provides an indication of the relative burning behavior of plastic foams. The sample is supported horizontally on a wire mesh and the test is conducted similarly to ASTM D-635 above. Although comparisons among similar materials may be reasonably valid, extrapolation to actual use conditions is usually not warranted because of the sensitivity of response to such configurational factors as density and thickness of the foam and intensity of the igniting flame.

Flammability of Finished Textile Floor Covering Materials (ASTM D-2859)--This test is used for carpets and rugs and has been adopted as DOC FF 1-70, Federal Carpet Flammability Standard by the Department of Commerce. In this test, a methenamine tablet is placed in the center of a preconditioned 9-inch square of carpet. The tablet is ignited with a match and burns for 90 seconds during which time the carpet will ignite and continue to burn or extinguish with the tablet. If the carpet burns beyond a 3-inch radius in any direction, the specimen fails. This test does not measure smoke or toxic gas emission. Although reproducibility is highly dependent on the physical structure of the carpet, the test is a reasonably reliable measure of response to such ignition sources as hot coals or a burning cigarette dropped onto a carpet. The test does not measure the performance of the carpet when heat from nearby burning materials is available to reinforce the ignition stimulus.

Federal Test Method Standard No. 191: Method 5903. Flame Resistance of Cloth; Vertical--A cloth specimen is mounted vertically in a 3-sided metal frame, with the lower free end positioned above the igniting gas burner. The burner flame is applied vertically at the middle of the lower end of the cloth for a period of 12 seconds. This test has been used with many variations mainly in specimen dimensions. Although one version of this test is specified for acceptance of children's sleepwear

(DOC FF 3-70), its correlation or relevance to real life usage is questionable. Test results have been demonstrated to be sensitive to the nature and intensity of the ignition source, and contradictory results are obtained with such other sources as the flame from a match, 3-second exposure to the bunsen flame, and radiation from an electrically heated coil. Under such circumstances, one might suspect that materials that pass the test may perform poorly under certain real ignition conditions, and, conversely, that materials failing the test may perform well under certain real exposures.

Standard Method for Measuring the Density of Smoke from the Burning or Decomposition of Plastics (ASTM D-2843)--The current standard acceptance test method for smoke production by plastic material is commonly referred to as the XP-2 Smoke Density Chamber. In this test, a test specimen, enclosed in a chamber, is exposed to the flame of a propane torch. Smoke density is estimated optically along a horizontal path. Subjective estimates can also be made by observing the visibility of an illuminated exit sign located at the back of the chamber. This test is intended and used primarily for building code acceptance testing of plastic light-transmitting materials. It is also used, however, in a number of laboratories to obtain relative ratings of smoke generation from a large variety of plastic materials.

National Bureau of Standards Smoke Chamber--Among the several attempts made to develop small-scale tests for smoke generation, the NBS chamber appears to be gaining acceptance. In this test, a 3-inch square sample is exposed to a radiant flux (and a pilot flame, if desired) and the influence on the transmission of light through a vertical path in the chamber is recorded. Variations used include exposure in a ventilated or sealed chamber. This test, however, as with the XP-2 chamber, relies on optical obscuration as the only measure of smoke density. This places

an as-yet-unjustified reliance on the comparability of the particle size and degree of agglomeration of smoke generated in the chamber with those of real fires.

Surface Burning Characteristics of Building Materials (ASTM E-84)-- This well-known test, one of the two or three acceptance tests specified by nearly all building codes, takes place in a 25-foot tunnel. The test was originally designed to rate flame spread (notably over the surfacing materials of wall and ceilings in building hallways) on a numerical scale prescribed to give the response of asbestos-cement board a value of zero and red oak flooring a value of 100. It also offers evaluations of heat contribution and smoke, including products of combustion. In spite of a fixed configuration that requires the materials under test to form the top of the tunnel, it has been used to rate flooring materials. Although it is said to give reproducible flame spread results to within about 20 percent, thermoplastics create serious problems by sagging and flowing, causing thereby very large differences in results from one test to the next (Table 3). Attempts to correlate E-84 test results with full-scale tests have met with mixed results, the better correlations not unexpectedly corresponding to flame spread along ceilings in hallways. Table 4 compares flame spread and smoke density of some natural and synthetic materials as measured by this test.

Table 3

E-84 TUNNEL TEST RESULTS ON CARPETING AND OTHER FLOORING MATERIALS[40]

Material	No. of Tests	Flame Spread			Fuel Contributed			Smoke Density		
		Av	Max	Min	Av	Max	Min	Av	Max	Min
Wool Carpet	21	58	91	23	19	48	10	98	313	5
Acrylic Carpet	9	143	550	34	27	6	10	187	448	28
Acrylic/Modacrylic Carpet	8	50	69	34	13	22	0	181	341	98
Nylon Carpet	16	116	183	59	32	10	17	150	238	54
Vinyl-Asbestos Floor Tile	9	24	49	8	4	13	0	93	169	31
Vinyl Floor Tile	3	36	51	18	3	9	0	329	384	262
Vinyl Roll Flooring	6	56	210	13	10	25	0	128	253	8
Linoleum	4	238	314	191	209	384	68	322	467	120
Plastic Floor Coverings	5	46	80	13	7	9	4	118	224	8

Fire Tests of Building Construction and Materials (ASTM E-119)--This test, the basic method for determining fire endurance, makes use of full-sized structural units, such as walls, columns, and floors to complete the enclosure of a room-sized furnace whose temperature is increased with time. The structural unit is loaded mechanically to simulate the stresses commonly applied to such structural members. Additional imposed loads include a hose-stream of water. Among the several possible failure modes is an instrumentally measured temperature rise of the side of the member opposite the heat load. Principal criticisms of the E-119 center around its simulation of the fire environment.[41] For one thing, the ASTM Standard Time-Temperature Curve, which is the heart of the method and the concept of fire endurance, clearly does not take proper account of differences between structures and occupancies with their variable fuel loadings and degrees of ventilation. Second, the method neglects the heat contribution of the material being tested and in some circumstances it appears that the response of the material is influenced far less by the imposed heat than by the properties of the material's own combustion boundary layer.

Fire Tests of Roof Coverings (ASTM E-108)--This is really a series of three tests intended to evaluate the resistance of roofing materials to the effects--both flames and firebrands--of exposure to fires that originate outside the building on which the materials under test are to be installed. The materials are applied to an inclined roof decking in as close a simulation of their actual applications as is practical to achieve. The test series is composed of (1) an intermittent flame exposure whose frequency and duration are the principal determinants of exposure severity; (2) a flame-spread test, using a steady flame exposure for a predetermined duration, used to note the extent to which the roofing carries the flame beyond its point of exposure up the slope of the test section; and (3) a brand test in which the severity of exposure is established with artificial firebrands of different sizes.

As with most fire-test methods, the choice of test conditions and performance criteria is arbitrarily based on a combination of intuitive judgment and empirical evaluation of a largely qualitative nature. It may be noteworthy that the sizes of the test brands are quite large, suggesting that the severity may be out of proportion to practical situations. Recent research experience[42] indicates that brands as large as even the Class-C Brands (approximately 1-1/2 inches$^2 \times$ 3/4 inch) are infrequently incident, while hot, on neighboring structures during the burning of wood-containing buildings. On the other hand, the large brands are demonstrably more effective--perhaps disproportionately so--in starting fire, and it may, therefore, make good sense to concentrate the attention of the test method on these.

Corner-Wall Fire Test--The origin of this fire-spread test for wallboard is uncertain. It is described, without reference, in Forest Products Laboratory Report No. 1443, "Fire-Test Methods Used in Research at the Forest Products Laboratory," revised September 1959, but seems to have been adopted widely, if not universally, by agents of the insurance industry. Although it has never reached the status of a standard test method, the Underwriters' Laboratories, referring to it in UL Subject 1040, appear to have some plans to bestow upon it UL recognition. Its virtue seems to be its large-scale and semirealistic configuration. In its favor is the remarkably strong correlation of its flame-spread data with the FPL 8-foot tunnel test, which in turn is a reduced-scale counterpart of the ASTM E-84 tunnel.

In the Corner Test, wallboard to be tested is arranged in the geometry of a corner and a 5-lb wooden crib is burned at the base of the corner. Progress of the fire is followed visually and by temperature rise in strategically located thermocouples. After the crib has burned away, the wall is allowed to burn freely for a period of time before it is

extinguished if it does not self-extinguish. To the extent that this test duplicates the effects of mutual enhancement of a burning object and adjacent walls prior to a true flashover situation, it should represent a significant improvement in the simulation of such configurational factors over simple, small-scale tests.

Critique of Current Test Methodology--The major deficiency that appears to encompass the spectrum of fire test methods is the general lack of correlation with real life usage and fire environment. In some cases, new materials or products are being evaluated with tests that were designed for a different class of materials and usages. The expected match between test configuration and real life exposure is the exception rather than the rule.

Most developmental test methods in use today lack superimposed heating from an external source. A heat flux superimposed on the flaming test piece should provide a thermal environment closer to that of a real fire. This could apply to almost any of the test configurations in use. Thus, the development of a thermal index in terms of energy flux required to sustain burning could provide a more meaningful measure of the safety threshold of a material in specified fire environments.

In reviewing existing acceptance tests, it appears that they often totally neglect, or evaluate in some rather dubious fashion, the contributions to the fire made by the material in question. The long-standing emphasis in test methodology on evaluation of flammability, surface flame spread, and fire endurance and the relatively recent attempts to deny acceptance into building practices of any interior surfaces that may contribute unnecessarily to the hazards of smoke obscuration and toxicity have already been noted. But quite aside from the question of whether these efforts can really succeed, they may be largely in vain since building contents are not regulated by codes nor very generally by any

other incentives such as insurance rates. Testimony to the tragic error of this faith in fire-resistive construction without regard to what flammable contents may be added is being given time and again by the spectre of the high-rise building fires. It appears that it is in the building contents that most fires start and also that their contribution to the fire and its life hazards may totally negate the efforts of the architects, builders, building material suppliers, and code officials to ensure fire-safe construction.

The failure of current test methods to adequately evaluate the total heat and heat-release-rate contributed by a material to the fire is a well-recognized problem that has been receiving a respectable level of research attention. A heat-release-rate (HR^2) calorimeter designed for this purpose has been developed at Ohio State University and used to generate some very revealing information about heat release in representative materials and how it is affected by fire-retardant additives and imposed heat fluxes.[41]

Independently, the National Bureau of Standards has developed an HR^2 calorimeter of such accuracy and time resolution that it appears to be well on its way to achieving the status of a standard test method.[41] A scale-up (18 inches $\times$ 24 inch specimen) more versatile version of the NBS HR^2 calorimeter, that accepts specimens of 18 inches $\times$ 24 inch size and has a capability to evaluate ignitability, surface-flame spread, and fire endurance, is being built at Stanford Research Institute and will soon be available for research into heat release responses of materials under well-characterized heat loads that are representative of real fire environments. The long-standing quest for a laboratory technique to provide data directly related to real fire situations perhaps through the agency of some large-scale test such as the Corner Test appears nearing the end.

It is apparent that more work is required to develop methods for evaluating the response and life hazards of materials in realistic configurations under realistic fire conditions. These more powerful approaches will surely depend upon a fuller understanding of the basic processes of ignition and combustion and will require for their implementation measurements of some of the inherent characteristics of materials such as heat release rate and particle size, density, and composition of the smoke produced under well-characterized and variable conditions of atmospheric composition and of heat and fluid flow. The development of a thermal index analogous to the limiting oxygen index--to ascertain the energy flux required to sustain burning could provide a fundamental measure of the safety threshold of a material in specified fire environments. At the same time, biological research into the fundamentals of smoke toxicity is a critical necessity. When the basic information that such research will provide is available, together with a more complete description of the character of the fire environment, it will then become possible for the first time to achieve "designed fire safety."

IX THE TOXICITY OF PLASTICS AS COMPARED TO CONVENTIONAL MATERIALS

The major causes of death or incapacitation in real fire situations have been identified[43] as one or all of the following:

Heat and Flames

Presence of Carbon Monoxide

Deficiency of Oxygen

Presence of Other Gases

Presence of Smoke

Panic .

The factors of heat, including direct burns and thermal shock, and panic in a real fire can be considered as primary contributors to the cause of death. This would be especially true in well-ventilated fires where there is a plentiful supply of oxygen. Burns of over 50% of the body are frequently fatal, especially in children and older people, and deep burns of only 10% of the body can be disabling. Such burns are not unlikely, as temperatures in ordinary building fires can quickly climb beyond the usual tolerable limit of 150 to 160^{o}F and can reach temperatures as high as 1500^{o}F in high-rise buildings, where self-contained fires can reach massive proportions.

The life hazards, under fire conditions, of the volatile products evolved when materials undergo combustion, depend on the nature of the gases given off as well as their concentration, surroundings, and length of time of exposure. Any unfavorable combination of these factors may endanger life or health. The burning process itself may be separated into three steps, the first being a destructive distillation of the material producing gases whose nature depends on that material. The second involves the combination of oxygen with free carbon to form carbon monoxide (formed about the same time as dense smoke begins to form).

while the third, if sufficient oxygen is present, results in a combination of oxygen with the flammable gases formed in the first step, as well as with the carbon monoxide (to yield carbon dioxide).

It has been reported[47] that the toxic products of combustion, while carbon monoxide, and this compound must be considered in any case, under any fire situation. Carbon monoxide is insidiously toxic--it is a colorless, odorless gas, primarily absorbed through the respiratory tract, although absorption through uncovered skin has been demonstrated experimentally. Inhalation of 0.1 percent concentrations usually produces a warning dizziness or headache; however, inhalation of concentrations of 1 percent or greater leads to no sensory warnings, with fatal results. The general physiological response which can be expected from specific atmospheric levels of carbon monoxide is shown below.

PHYSIOLOGICAL RESPONSE TO CARBON MONOXIDE[43]

% CO in Atmosphere	Response
0.01	Allowable exposure for several hours
0.04 - 0.05	No appreciable effect after 1-hour exposure
0.06 - 0.07	Just appreciable effect after 1-hour exposure
0.1 - 0.12	Unpleasant after 1 hour
0.15 - 0.2	Dangerous when inhaled 1 hour
0.4	Fatal when inhaled for less than 1 hour
1	Fatal when inhaled for 1 minute

Physiological response is influenced by such factors as rate of breathing and individual susceptibility. The rate of breathing will obviously be increased in strenuous physical activity or in the times of emotional stress encountered in a real fire situation. Such an

increase tends to build up CO concentration in the blood. When inhaled, carbon monoxide combines with the hemoglobin of the blood to form carboxy-hemoglobin rather than oxyhemoglobin which transports oxygen to the tissues. Any increase therefore in CO inhalation may decrease oxygen delivery to the tissues and additionally, hinder removal of carbon dioxide from the blood stream.

A situation occurring as a natural result of combustion in any given fire situation is the depletion of oxygen. A summary of the physiological effects which may be expected at various atmospheric oxygen levels is given below.

PHYSIOLOGICAL EFFECTS OF REDUCED ATMOSPHERIC OXYGEN LEVELS[43]

% O_2 in Atmosphere	Response
21	None
17	Impaired muscular coordination; increased respiratory rate
12	Dizziness, headache, fatigue
9	Unconsciousness
6	Death in 6-8 minutes

Although atmospheric oxygen concentration dips to 3% or less have been recorded[43] in various experimental, poorly ventilated fires, a 15% oxygen level is usually required to support combustion of most burnable materials. It is possible, therefore, that a man could survive where fire could not, if oxygen deficiency were the only serious factor. In a fire, however, as oxygen supply decreases, carbon monoxide concentration generally increases, and the oxygen supply in the blood then comes under a double strain. These effects, in combination with the others mentioned, may produce serious, possibly fatal physiological effects.

Carbon dioxide and a large number of other gases may also be produced in fires. Carbon dioxide, the gas produced in all fires, is toxic by itself, but only in high concentrations. The more common materials will, when burned, produce poisonous compounds that are similar to those produced by various types of plastics. Wood, while burning, will produce formaldehyde and acetic acid in fractions of a percent. Wool will give off hydrogen cyanide, as will silk, leather, and even cheese. A comparison of the amount of hydrogen cyanide in the pyrolysis products of some natural and synthetic materials pyrolyzed in air and nitrogen is given below.

DETERMINATION OF HYDROGEN CYANIDE IN PYROLYSIS PRODUCTS[45]

Material	Hydrogen Cyanide micrograms/gram sample)	
	Air	Nitrogen
Paper	1100	182
Cotton	93	85
Wool	6500	5900
Nylon	780	280
Polyurethane Foam	1200	134

Other gases which may form include nitrogen dioxide, ammonia, hydrogen chloride, and sulfur dioxide. Most of these display characteristic odors and irritating effects at sublethal concentrations. All are lethal in high concentration and with prolonged exposure.

Smoke

Smoke is a complex mixture of heated gases, liquid droplets, and solid particles evolved from combustion. Smoke includes materials such as acids, alcohols, aldehydes, and hydrocarbons. Wood smoke, for example,

contains aldehyde, acrolein, a strong irritant. In some cases,[43] organic acids and aldehydes which are liquid at ordinary temperatures appear to condense on the surface of smoke particles and cause more irritation than the actual particles which are mostly carbon. The heat in smoke, which can cause tissue injury in itself, may enhance the toxic effects of any airborne particles contained in the smoke.

It is now widely recognized[46] that a large share of the annual deaths from fire are really due to smoke intoxication and there is considerable interest in regulating the use of materials that may burn to produce toxic gases. Attempts to legislate a solution to the toxicity problem is contained in recent changes to the building code of the City of New York, requiring that "no material shall be used in any interior location that upon exposure to fire will produce products of decomposition or combustion that are more toxic in point of concentration than those given off by wood or paper when decomposing under comparable conditions." This code change, admirable as it is in its intention, cannot be implemented in any meaningful way. The state of the art will simply not permit any really satisfactory test method to be prescribed to serve the needs of such a change in the code. Small-animal tests have been employed for such purposes in the past, but the outstanding conclusions one gains from small-animal studies is that, when it comes to respiratory toxicity, small animals are not good analogs for man.[47]

Smoke poisoning, from a medical point of view, may present a complex and sometimes poorly defined picture of illness. The results of breathing combustion products may be simply those due to the inhalation of carbon monoxide. This gas is probably part of all smoke poisoning in a greater or lesser degree, depending on circumstances. The major uncertainties preventing the establishment of rational test methods for smoke intoxication center around the question of whether there are really any bonafide

effects other than anoxia involved. While it is prudent, until the subject is satisfactorily resolved, to be concerned about the production of such irritating substances as acrolein from cellulosics and hydrochloric acid from polyvinyl chloride, of such highly poisonous gases as phosgene from chlorine-containing polymerics and hydrocyanic acid from nitrogenous materials, there is an impressive lack of evidence that they are really implicated in any practical way. With the principal exceptions of the well-documented cases of delayed edema--which are as satisfactorily explained from inhalation of hot air as from a chemical irritant--and limited reports of hydrogen cyanide poisoning in aircraft crash fire victims, there is every reason to suspect that anoxia caused by inhalation of carbon monoxide (synergistically enhanced with heat and carbon dioxide, perhaps) is the cause of death in nearly all such cases. Accordingly, a major contribution to the solution of this problem can be made through research than can establish or refute this point without equivocation. If it is established, then one can confidently proceed with development of instrumental (nonbiological) tests.

In summary then, the only apparently uniform features in the toxicology of burning plastics appear to be those of the toxicology of fire-heat, carbon monoxide, oxygen depletion, other combustion gases, and smoke. In the evaluation of plastics, the hazard from combustion or thermal decomposition should be compared under equivalent conditions with that of alternative materials which have, if possible, a history of similar use. This comparison should provide the basis for present assessment of hazard, as well as the more standardized evaluation anticipated in the near future.

X THE PLASTICS INDUSTRY'S MANDATE

—DIRECTION AND ACTION—

The Society of the Plastics Industry has, for a number of years, been active in the areas of flammability. As early as 1962, SPI sponsored work with the Underwriters' Laboratories (UL) and, more recently, SPI has contributed significantly to work done by the Illinois Institute of Technology Research Institute (IITRI) looking toward the correlation of test results and full-scale fires. SPI members have participated in the work of the ASTM Committee E-5 (Fire Tests) and the D-20:30 (Plastics Flammability). In addition, SPI has submitted comments on a number of occasions stating its members' views with regard to government proposals for flammability standards. Meaningful recommendations consistent with overall best interests of public safety have been offered in this way.

Presently, SPI recognizes its ever-increasing responsibility relating to the safe use of plastics, continues to address itself to the problems of defining and minimizing the possible hazards associated with plastics flammability. There are several factors that make the achievement of these goals most difficult. One of these is the industry's ability to engineer plastics to meet an almost endless variety of end-use performance requirements. The second factor is the seemingly endless growth of the new applications for these engineered plastics. Each potential hazard must be evaluated in relation to each environment in which a particular plastic is proposed for use.

Specific problem areas currently receiving SPI's attention include the present general lack of correlation between basic science and scale testing and most real-fire situations. In this regard, SPI has undertaken, to the best of its financial ability, test programs at several institutions to develop this essential correlation. Regrettably, to date these efforts have left much more work to be done.

Other activities of the SPI have been in the field of education. This education must include, among others, the architect, the engineer, specifier, code official, and firefighter. SPI, through its Plastics in Construction Council's Code Advisory Groups and its plastic pipe Institute's standards and code activities, as well as its Furniture and Appliance Council's seminars has been making a major contribution toward this goal.

Additionally, at the request of the National Science Foundation, SPI provides representatives to consult on some of the many RANN (Research Applied to National Needs) programs on fire safety. SPI's Furniture Council, in answer to a request from the Port Authority of New York City, is preparing a review of test methods and standards proposed for furniture in high-rise buildings. SPI is following closely the development of the systems engineering approach used by the General Services Administration and regulatory officials in the United States. Full scale tests are being sponsored by the SPI in cooperation with insurance agencies concerning storage of film wrap pallets and of cellular products used as thermal insulation. The Plastics Pipe Institute is providing a research associate to the National Bureau of Standards to work on its HUD sponsored comprehensive study of plastic pipe, including its use in fire-rated high-rise buildings.

In other specific areas within the industry, the Urethane Safety Group of SPI recently contracted with Southwest Research Institute for a state-of-the-art review of urethane foam flammability considerations, including toxicity. This study should lead to a definition of specific areas of required fire testing for these materials. A new SPI subcommittee has been appointed to review immediately, at the request of the Food and Drug Administration, the safe use of shredded plastic grass used in Easter baskets. Another subcommittee, in cooperation with the Society of Automotive Engineers (SAE), provides guidance in understanding,

standardizing, and complying with the tests outlined in Motor Vehicle Safety Standard No. 302. Additionally, assistance is being given to the New York Transit Authority in consideration of smoke control in subway systems, and presentations on the "Flammability, Smoke and Toxicity of Plastics" are given to groups such as the National Safety Council to further the educational goals of the Society.

In the future, in addition to funding such programs in the areas of fire research, the Society has set five major tasks:

(1) To better define the important problems associated with flammability

(2) To supply better information and education on plastics in general and on the specific effects concerning flammability, smoke, and toxicity

(3) To assist any and all regulatory agencies in their attempts to reduce all flammability problems

(4) To commission studies regarding specific hazards related to plastics

(5) To assist as a "clearing house," or source of coordination relative to this overall area.

The Society is dedicated to continuing these efforts to the limit of its financial capabilities. Within the membership exists the required expertise which stands ready to cooperate with all concerned agencies and groups. Such work has already begun and is planned to continue until the fire problem is met.

XI THE OVERALL NEEDS

The summary and analysis of the socio- and technoeconomic aspects of fire prevention and control, with special emphasis on the materials aspects of these problems, points out the following key requirements which still need attention.

Systems Approach - Detecting, Warning, Venting, and Extinguishment

Until recently, too great an emphasis was placed on materials problems when real-fire situations were confronted. In our rapidly growing industrialized society with a vast diversity of materials potentially involved in many types of fires, this emphasis must change. A coordinated systems approach is needed taking into account not only materials but the way they are used in the final product configuration and how their ignition can be avoided; or if it cannot be avoided, how it could be detected at the earliest possible moment and extinguished.

From an engineering point of view, these problems, along with the problem of properly warning people away from a fire without causing panic, must be of high priority. Projects, such as the General Services Administration office building in Seattle, and others, are going far toward answering many of these questions. More must be done, however, to ensure an overall attack on the fire problem.

The Need for Relevant Scale Tests Relating to Real Fires

Current test methods are generally inadequate for the full and meaningful evaluation of the broad spectrum of materials under consideration. This inadequacy is due in large part to a lack of relatedness to reality that often stems from incomplete simulation of fire conditions or of the configuration of the material as it is used. It is also due to a neglect,

or at best an improvised treatment, of the contribution made to the fire environment and its life hazards by the material under test. The philosophy of gaining acceptance for a material's usage by causing it to pass a prescribed test, however relevant, has fostered this situation. For real-life safety, however, a new series of scale tests--relevant and responsive to the real world--must be promulgated, and new criteria designed based on these tests.

The Need for Concerted Effort Toward Standard Test Development

If a new series of tests, such as those described above, were to be unilaterally developed and implemented by the plastics industry alone, little or no impetus for their use outside the industry could be expected. If such tests, however, were developed by the plastics industry, within the framework of a voluntary consensus standards organization, with representatives of government and regulatory agencies working in concert, not only could such tests expect wide promulgation and acceptance, but also their life-safety and real-world relevancy would be improved many fold. Cooperative effort in this field must be achieved for the optimization of life-safety in future fire situations and the prevention of disastrous holocausts in the United States and other countries.

Broader Education and Dissemination of Available Information

To many segments of the population, plastics are still a new, different, and relatively unknown class of materials. This situation still exists though plastics and plastics products have proliferated into almost every aspect of industrialized society. Being different and probably somewhat misunderstood, plastics have come under considerable suspicion in fire situations. As was previously stated in this report, plastics are different from conventional materials; however, no factual data have yet been

generated to show that these materials, taken as a class, represent any more or less of a life hazard during a fire situation than do the conventional materials, such as wood, paper, wool, or any others. Information on the fire hazards of plastics materials written for the clear understanding of the layman, factually, concisely, with a minimum of technical terms must be disseminated to begin the education of those with little knowledge of the plastics field. Additionally, more sophisticated versions of such information, describing flammability tests, illustrating test results, depicting real-fire conditions, but still in relatively nontechnical language, must be promulgated throughout the fire community. As a clear understanding of plastics and plastics products develops, the plastics industry will find itself dealing with a more responsive industrial community and another step toward concerted efforts for preserving life safety will have been made.

From an engineering point of view, these problems, along with the problem of properly warning people away from a fire without causing panic, must be of high priority. More must be done, however, to ensure an overall attack on the fire problem.

Concerted Effort with Insurance Companies, User Industries, and Government Agencies for Information Exchange, Evaluation, Study, and Education

For any of the areas outlined above to succeed, representatives of all interested parties must be able to discuss their problems, putting them in the proper perspective, and then working together to solve them. Only with all parties informed of each others' problems and needs will open communication between them be possible. Only with open communication between these industries and agencies will the fire problem be solved.

XII THE OVERALL RESPONSE

The response which must come not just from the plastics industry, but from all industries, agencies, and governmental bodies involved in the fire problem is clear. It must be multifaceted, vigorous, and immediate. Work must begin at the earliest opportunity and proceed until the life hazard and property losses from a real-fire situation are eliminated.

Research and Development

Some of the key areas in which intensified research efforts must be expended include:

- Further development of systems engineering approaches similar to that used by the GSA and regulatory officials. Such efforts would encompass the expertise of materials producers, designers, and engineers, working together to establish concepts relating to overall fire and preparedness, as well as methods of warning, traffic control during evacuation, and techniques of extinguishment.

- Basic research on the mechanisms of fire retardancy and smoke generation. Such efforts must be aimed at a fuller understanding of how and why things burn and thus how they can be prevented or retarded from doing so.

- Development of new synthetic materials which resist ignition. The synthesis of inherently noncombustible materials, or probably at best slow-burning materials, would implement a systems approach in allowing a longer detection time and a longer warning time for extinguishment or evacuation.

- Implementation of basic biological studies of smoke toxicity using larger animals such as sheep as well as smaller animals such as mice and rats in an attempt to more closely approximate man's physiological response to the combustion products of burning materials.

- Development of new tests based on measurements of the inherent characteristics of a material such as its rate of heat release, the nature and composition of its smoke, and its basic response to well-characterized test conditions.

Though much needs to be done, technological advances in these areas will go far to bringing the industry to a position from which it may hope to largely eliminate the life-hazard problems of fire.

Level of Effort and Costs

It is difficult to assess the costs of these many programs. Most would take one to three years to generate meaningful data. Most would cost in the neighborhood of one million dollars. However, if even all were immediately funded, the expense would be a mere fraction of the over $2.6 billion lost annually in property damage due to fires in the United States alone. At this point a discussion of costs is a luxury that cannot be afforded; this work must be accomplished if fire hazard is to be controlled.

Fire Test Methods

In view of the indictment that can be brought against many fire test methods with particular reference to their relation to real life, a review of the process of establishing regulatory standards and specifications for items of commerce is recommended. It is suggested that in many cases regulatory actions be taken without benefit of all pertinent information. To promote life-safety through design of realistic tests, it is recommended that standards be developed by cooperative action among all interested parties. This type of government-industry cooperation might be implemented by the possible formalization of the presently existing voluntary consensus standards organizations composed of representatives of government and regulatory agencies, manufacturer and user industries and enjoining them with the responsibility for establishing realistic and meaningful standards.

Education Information, and Cooperation

The Society of the Plastics Industry must continue its efforts to disseminate all available information relating to fire problems, smoke generation, toxicity, fumes, and test methods to the community at large, with special reference to architects and builders, code officals and legislators, insurance companies, the fire community, and member companies within its own industry. Clear and factual information on plastics materials, written in a way that all can understand, should be prepared and disseminated as far as possible. Such an effort can be supplemented by educational seminars, movies, and lectures. Working closely with the fire community, educationalprograms on fire prevention and control for all materials can be generated and distributed. This job is an endless one; however, the potential results from its successful accomplishment--the elimination of much of the fire hazard by an educated public--seems worth the effort.

XIII CONCLUSIONS

Four major conclusions can be drawn from this study. They are:

(1) There is no plastics fire problem; it is instead a materials and use fire problem. All evidence to date points to the fact that, generally speaking, plastics burn in a manner no more or no less hazardous to life than the more conventional materials such as wood, paper, or wool.

(2) Considerable research and development in materials and systems engineering approaches must be accomplished before the fire problem is minimized.

(3) Many of the present laboratory test methods appear inadequate in their relation to the real world. Though it is generally agreed that larger scale tests are relevant and tend to be meaningful, they are still too cumbersome and costly for generalized use. New tests, more expressive of real-life fire situations must therefore, be developed and implemented if life safety is to be protected.

(4) The only way major progress toward this goal will be achieved is through the concerted efforts and close cooperation of the plastics industry, building officials, governmental regulatory agencies, the fire community, insurance companies, and the community at large. The objective can be achieved through education, study, and information exchange among all these groups, building a foundation of trust and communication.

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